A Union of Professionals

Professional Learning

QUESTIONS TO PROMOTE SCIENTIFIC INQUIRY AND ENGINEERING DESIGN

An AFT Resource to Promote Science Education

A Union of Professionals

OUR MISSION

The **American Federation of Teachers** is a union of professionals that champions fairness; democracy; economic opportunity; and high-quality public education, healthcare and public services for our students, their families and our communities. We are committed to advancing these principles through community engagement, organizing, collective bargaining and political activism, and especially through the work our members do.

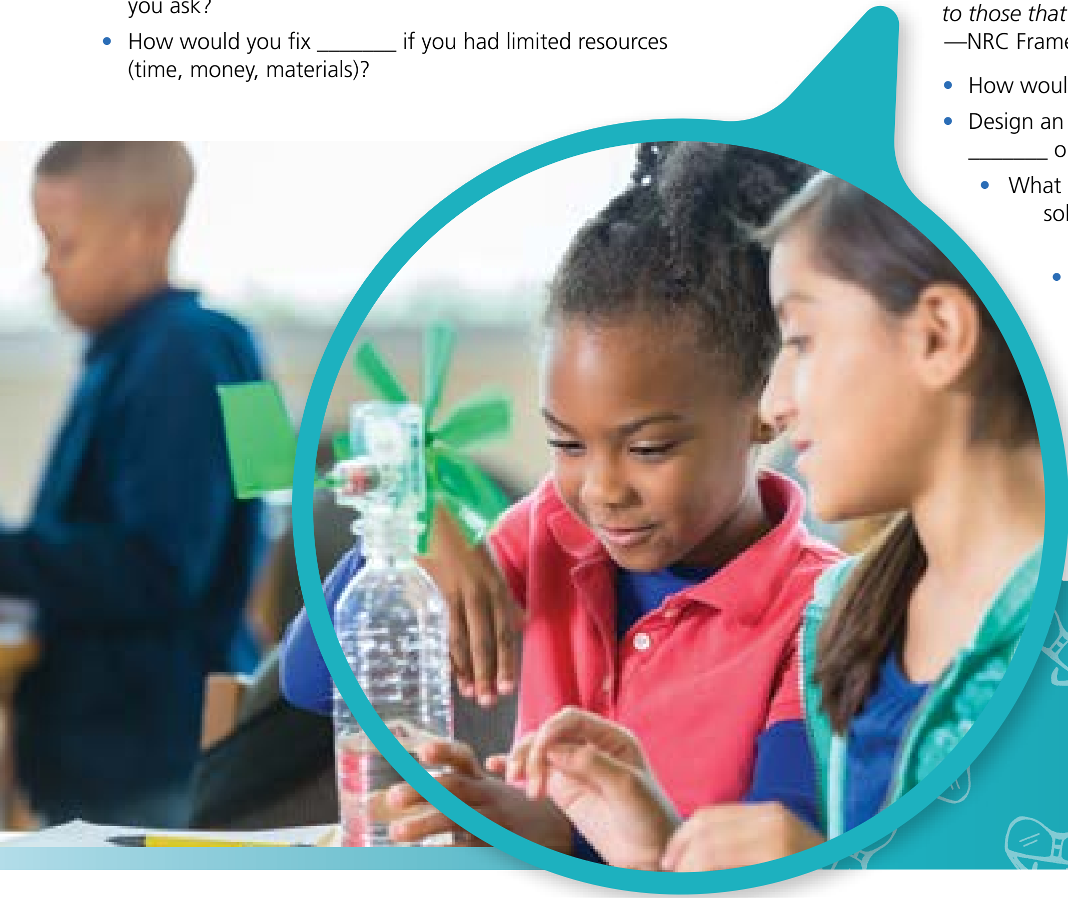
Questions similar to the ones presented here should be considered as teachers implement the Next Generation Science Standards (NGSS) and individual state science standards. Many of these questions are useful in helping students develop and use the NGSS Science and Engineering Practices. Others are meant to focus students on important ideas in science. Both types of questions are necessary to develop scientific proficiency. These lists are not definitive, and teachers should add their own questions. Although these questions appear under specific headings, the thought processes and content knowledge required to answer them are intertwined. The answers elicited should integrate and connect ideas.

QUESTIONS AND PROMPTS TO ENGAGE AND BUILD SCIENCE AND ENGINEERING PRACTICES

Engaging in the practices of science helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the wide range of approaches that are used to investigate, model and explain the world. Engaging in the practices of engineers likewise helps students understand the work of engineers, as well as the links between engineering and science.

The best way to ensure a practice is being used for science or engineering is to ask about the goal of the activity. Is the goal to answer a question? If so, students are doing science. Is the purpose to define and solve a problem? If so, students are doing engineering.—Appendix F: Science and Engineering Practices in the NGSS

1. Asking Questions and Defining Problems. *Students at any grade level should be able to ask questions of each other about the texts they read, the features of the phenomena they observe, and the conclusions they draw from their models or scientific investigations. For engineering, they should ask questions to define the problem to be solved and to elicit ideas that lead to the constraints and specifications for its solution.*—National Research Council. 2012. A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press.
   - Do you see _______? What do you think makes that happen?
   - What causes _______ to happen? How can we find out?
   - Suppose you needed to _______, but could not find a tool to help you. What could you do?
   - How could you get a different result?
   - What causes ____? Could you prove that? If so, how?
   - Is your question testable? How can you test your question?
   - When you look at _______, what kind of questions might you ask?
   - How would you fix _______ if you had limited resources (time, money, materials)?



2. Developing and Using Models. *Modeling can begin in the earliest grades, with students' models progressing from concrete "pictures" and/or physical scale models (e.g., a toy car) to more abstract representations of relevant relationships in later grades, such as a diagram representing forces on a particular object in a system.*—NRC Framework, 2012, p. 58
   - How could you show how the _______ works?
   - Explain how you could use toys/objects to represent the effect of _______ on _______.
   - In what way could you demonstrate the process/system of_______?
   - Which model or models could you use to help explain these phenomena?
   - What limitations does your model have in testing_______?

3. Planning and Carrying Out Investigations. *Students should have opportunities to plan and carry out several different kinds of investigations during their K-12 years. At all levels, they should engage in investigations that range from those structured by the teacher—in order to expose an issue or question that they would be unlikely to explore on their own (e.g., measuring specific properties of materials)—to those that emerge from students' own questions.* —NRC Framework, 2012, p. 61
   - How would you find out _______?
   - Design an investigation to test the effects of _______ on _______.
   - What information will be needed to find the solution to a problem? How will you go about gathering that data?
   - What would you use to measure _______? Why?
   - Which procedure would you use to compare the _______ of certain materials?
   - What structural design could be used to solve_______?
   - Predict what would happen if _______.

4. Analyzing and Interpreting Data. *Once collected, data must be presented in a form that can reveal any patterns and relationships and that allows results to be communicated to others. Because raw data as such have little meaning, a major practice of scientists is to organize and interpret data through tabulating, graphing or statistical analysis. Such analysis can bring out the meaning of data—and their relevance—so that they may be used as evidence. Engineers also make decisions based on evidence that a given design will work; they rarely rely on trial and error. Engineers often analyze a design by creating a model or prototype and collecting extensive data on how it performs, including under extreme conditions. Analysis of this kind of data not only informs design decisions and enables the prediction or assessment of performance but also helps define or clarify problems, determine economic feasibility, evaluate alternatives and investigate failures.*—NRC Framework, 2012, pp. 61-62
   - How would you record your observations so that someone could understand a phenomenon?
   - What would you use to show the changes of _______ over time?
   - What type of table or graph best represents the data collected? Provide evidence to support your choice.
   - Identify the type of data being collected and explain why it's useful in supporting scientific claims. (qualitative vs. quantitative)Compare and contrast two different data sets and report your findings.
   - Use data to explain _______.

5. Using Mathematics and Computational Thinking. *Although there are differences in how mathematics and computational thinking are applied in science and in engineering, mathematics often brings these two fields together by enabling engineers to apply the mathematical form of scientific theories and by enabling scientists to use powerful information technologies designed by engineers. Both kinds of professionals can thereby accomplish investigations and analyses and build complex models, which might otherwise be out of the question.*—NRC Framework, 2012, p. 65
   - Calculate _______ using the formula and data provided.
   - Do you need to make any unit conversions?
   - Use a mathematical formula to support/justify an explanation.
   - How is it possible to represent qualitative evidence as quantitative data?
   - Which tool or mathematical concept could be used to test your proposed solution?
   - Describe the algorithm you would use to solve this problem.

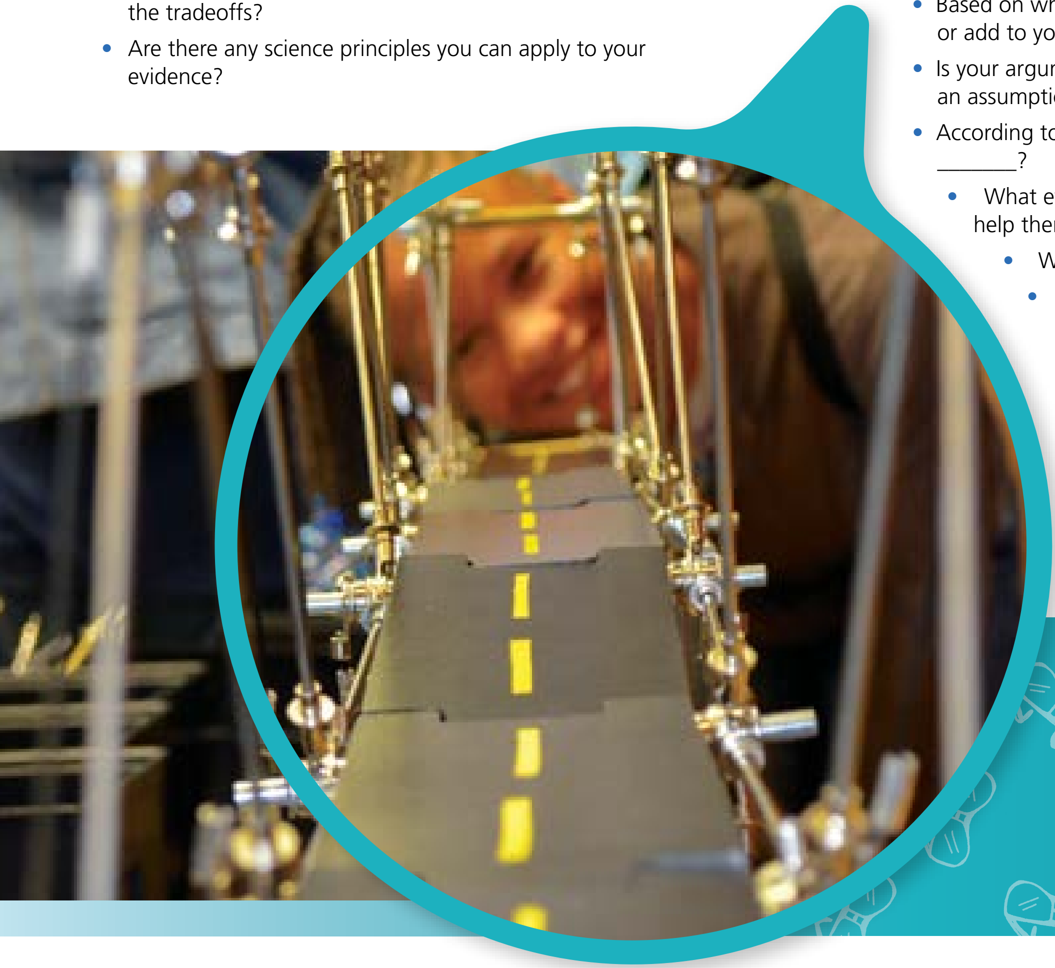
6. Constructing Explanations and Designing Solutions. *An explanation includes a claim that relates how a variable or variables relate to another variable or a set of variables. A claim is often made in response to a question and in the process of answering the question, scientists often design investigations to generate data.*

The goal of engineering is to solve problems. Designing solutions to problems is a systematic process that involves defining the problem, then generating, testing and improving solutions—Appendix F: Science and Engineering Practices in the NGSS

- What do you notice about the phenomena?
- Are there any other solutions to this problem?
- What evidence do you have that supports your claim?
- How does _______ solution compare to your solution?
- Based on your observations, what do you predict would happen if you make a change to variable A?
- How does your data support your claim?
- If you were to change _______ in your design, what are the tradeoffs?
- Are there any science principles you can apply to your evidence?
- Based on your evidence, is it reasonable to deduce _______?
- What structural design would best be used to solve_______?

7. Engaging in Argument from Evidence. *Argumentation is a process for reaching agreements about explanations and design solutions. In science, reasoning and argument based on evidence are essential in identifying the best explanation for a natural phenomenon. In engineering, reasoning and argument are needed to identify the best solution to a design problem. Student engagement in scientific argumentation is critical if students are to understand the culture in which scientists live, and how to apply science and engineering for the benefit of society. As such, argument is a process based on evidence and reasoning that leads to explanations acceptable by the scientific community and design solutions acceptable by the engineering community.*—Appendix F: Science and Engineering Practices in the NGSS

- Is that an opinion or evidence? Explain your reasoning.
- Based on what _______ said, would you like to change or add to your explanation or claim? Why or why not?
- Is your argument based on the evidence collected or an assumption in your claim?
- According to the data collected what would happen if _______?
- What evidence or data could you give _______ to help them improve their design?
- Why do you think that's the best solution?
- What inconsistencies, if any, did you find with that claim?
- What criteria will you use to _______?



8. Obtaining, Evaluating and Communicating Information. *Being able to read, interpret and produce scientific and technical text are fundamental practices of science and engineering, as is the ability to communicate clearly and persuasively. Scientists and engineers employ multiple sources to obtain information used to evaluate the merit and validity of claims, methods and designs. Communicating information, evidence and ideas can be done in multiple ways: using tables, diagrams, graphs, models, interactive displays and equations as well as orally, in writing and through extended discussions.* —Appendix F: Science and Engineering Practices in the NGSS
   - Based on the readings, what central ideas are consistent throughout?
   - Are there any patterns that can be identified in the readings?
   - How could you best report your findings to your classmates? Community? Parents? The scientific community?
   - What kind of table, graph or diagram would best show your results?
   - Is the evidence provided quantitative or qualitative?
   - What is the validity of your sources?

QUESTIONS AND PROMPTS FOCUSING ON CROSSCUTTING CONCEPTS

Crosscutting concepts have application across all domains of science. As such, they are a way of linking the different domains of science. They include patterns; cause and effect; scale, proportion, and quantity; systems and system models; energy and matter; structure and function; and stability and change. The Framework emphasizes that these concepts need to be made explicit for students because they provide an organizational schema for interrelating knowledge from various science fields into a coherent and scientifically based view of the world. http://ngss.nsta.org/CrosscuttingConceptsFull.aspx

1. Patterns. *Observed patterns of forms and events guide organization and classification, and they prompt questions about relationships and the factors that influence them.* —Appendix G: Crosscutting Concepts in the NGSS
   - What sort of patterns do you notice occurring?
   - Based on what you observed, what would happen if _______?
   - Using your observations, predict what will happen if _______?
   - Given the graph identify any trends?
   - Based on the graph, what is the relationship between the variables?
   - Based on the trends you see in the graph or table, predict what will happen when _______ is changed?
   - How will this cycle change over time?
   - Describe how _______ is similar or different to _______.

2. Cause and Effect. *Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.*—Appendix G: Crosscutting Concepts in the NGSS
   - What is the relationship between _______ and _______?
   - Based on the relationship between _______ and _______, what would happen if _______?
   - Are there multiple causes affecting your system?
   - Does each cause have the same and/or equal effect on your system?
   - Design a test to identify causal relationships and use these relationships to explain _______.

3. Scale, Proportion and Quantity. *In considering phenomena, it is critical to recognize what is relevant at different measures of size, time and energy and to recognize how changes in scale, proportion or quantity affect a system's structure or performance.*—Appendix G: Crosscutting Concepts in the NGSS

- Is the object bigger than _______?
- Is the object smaller than _______?
- Why is _______ an appropriate measurement tool/unit for _______?
- Rank the following items from hottest to coldest: _______.
- Looking at your data, where does _______ fit in comparison to _______?
- How many _______ would make _______?
- What is the relationship of _______ and _______?
- How does the ratio or rate change over time?
- How does an increase/decrease in the rate change the impact?
- What is the scale it is measured in? How would a scale that is _______ change your perception of the trend?

4. Systems and System Models. *Defining the system under study – specifying its boundaries and making explicit a model of that system – provides tools for understanding and testing ideas that are applicable throughout science and engineering.*—Appendix G: Crosscutting Concepts in the NGSS

- Why is the shape of _______ needed for _______ to operate?
- Why does the size of _______ affect the work of _______?
- Describe a process that is similar to _______.
- How does _______ work in comparison to _______?
- Will _______ operate properly without _______ present?
- Looking at one part of the system, are all the components in that one part accessible or comprised of another part? Why or why not?
- How does energy/matter move through this system?
- What parts of the system are not included in the model?
- How could you refine a model of the system to include _______?

5. Energy and Matter. *Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.*—Appendix G: Crosscutting Concepts in the NGSS

- What can be made from _______?
- As energy flows through this system, is anything new made?
- Looking at _______, what is it made of?
- Are those components used in any other part of the system?
- During a chemical change, what happens to the _______?
- During a nuclear reaction, what material undergoes a change? What happens to the components of the initial material?

- When exploring an environment, how does matter from a plant affect the life of an animal?
- _______ represents energy transforming from _______ to _______.
- What changes are made in matter to make it available to an organism?
- How does the energy in _______ ultimately trace back to the sun?

6. Structure and Function. *The way in which an object or living thing is shaped and its substructure determines many of its properties and functions.*—Appendix G: Crosscutting Concepts in the NGSS
   - Observe _______ and predict what each part's function is in relation to the whole.
   - Thinking about _______, what else could be used to do the same job?
   - Thinking about _______, what other material could be use to make that item lighter in weight? Stronger in material?
   - How does the structure of the _______ allow for it to be a good source of _______?
   - What structure is present in the body to do _______?
   - Explain how the structure of _______ is adapted to perform the function of _______.

7. Stability and Change. *For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.*—Appendix G: Crosscutting Concepts in the NGSS
   - Observe a system for a period of time. What has changed in the system? What stayed the same?
   - If water is added, what happens to the system?
   - If the system is exposed to heat, what changes if any occur? Explain if the change is permanent.
   - What changes can a human make that will destroy or permanently alter the environment?
   - How does the _______ change the stability of the system?
   - Describe how _______ regulates the system.
   - How is a physical change to the system different from a chemical change to the system?

ASK THE RIGHT QUESTIONS

Each step in the instructional sequence you design should integrate the three dimensions (practices, disciplinary core ideas, and crosscutting concepts) into a single learning performance. As you write your learning performances, you may want to focus on these questions:

- What are some commonly held student ideas (both troublesome and helpful) about this topic? How could instruction build on them?
- What prior concepts do students need to learn to understand the core ideas? What level of abstraction is expected of them?
- What representations or media help students make sense of core ideas?
- What practices could students engage in to explore phenomena and/or representations of this concept?
- Are there crosscutting concepts that could support learning the core idea?
- What connections to other core academic content could be emphasized as students engage in the instructional sequence?

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